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Alexandria, VA 22313-1450

Sir:

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CLAIM OF PRIORITY

We file herewith a certified patent application, bearing application number 2,413,218, which was filed on November 29, 2002, and on which the above U.S. application was based. We ask that this U.S. application be awarded priority rights in accordance with Section 119 of Title 35, Patents, (Public Law 593).

Respectfully submitted,

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Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,413,218**, on November 29, 2002, by **MEASUREMENT MICROSYSTEMS A-Z INC.**, assignee of Andrzej Barwicz, Roman Z. Morawski, Mohamed Ben Slima, Andrzej Miekina and Michal P. Wisniewski, for "Flash Optical Performance Monitor".

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February 25, 2004

Date

Canada

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OPIC CIPO

Abstract of the Disclosure

A flash optical performance monitor for monitoring DWDM channels is disclosed. The monitor is to assess the spectral quality of light received and to determine from changes in the spectral quality, relative to a known spectral quality indicative of an acceptable signal, an estimate of signal quality. The flash optical performance monitor comprises a spectrometric transducer for performing a spectral decomposition of the light received, and for transforming the decomposed optical signal into electrical-domain data, a memory for storing advanced digital signal processing routines, and a processor in connection with the wavelength optical unit and with the memory. The processor receives the advanced digital signal processing routines and the electrical spectral data, and applies the advanced digital signal processing routines to the electrical spectral data. Also disclosed a method for monitoring a quality of data transmission of at least one optical channel. The method comprises the steps of capturing a spectrum of a light signal transmitted on the at least one optical channel at an instance in time, providing a spectrum of a time-domain signal, performing an analysis of the spectrum to determine a quality of the light signal, and determine from the quality of the light signal a quality of data transmission.

Flash Optical Performance Monitor

Field of the Invention

[001] The present invention relates to the field of optical performance monitoring as currently applied in dense wavelength-division multiplexing, and more specifically to advanced optical performance monitoring performed *in situ* and without the requirement of a known specific test signal.

Background of the Invention

[002] The explosive expansion of telecommunications and computer communications, especially in the area of the Internet, has created a dramatic increase in the volume of worldwide data traffic that has placed an increasing demand for communication networks providing increased bandwidth. To meet this demand, fiber-optic networks and dense wavelength-division multiplexing (DWDM) communication systems have been developed to provide high-capacity transmission of multi-carrier signals over a single optical fiber. In accordance with DWDM technology, a plurality of superimposed concurrent optical signals is transmitted on a single fiber, each signal having a different central wavelength. In wavelength-division multiplexed (WDM) networks, optical transmitters and receivers are tuned to transmit and receive on a specific wavelength.

[003] With the widespread deployment of DWDM optical networks, knowing precisely what is happening at the optical layer of the network is quickly becoming a real-time issue for network management. Stable and protected DWDM links cannot be realized without real-time optical monitoring at each channel. For example, as the number of channels deployed in a WDM optical network increases, say from 40 to 80 or 160, wavelength drifts and power variations are more likely to cause data errors or transmission failures. It is therefore becoming important for network management to dynamically monitor the performance of the communication channels in order to supply the corresponding decision-support systems with information necessary for fault detection and identification, as well as for undertaking efficient restoration actions. To achieve this goal, a new type of fiber-optic products has been developed, the so-called optical performance monitors (OPM).

[004] An OPM consists of a spectrometric transducer, containing an optical unit combined with a detection unit, and an electronic processing unit. The optical unit separates the wavelength components of the multiplexed signal containing a plurality of wavelengths; its functioning is usually based on a dispersive element or a tunable filter or a tunable laser. The detection unit is as a rule a detector array and is used to convert the optical signal to an electric signal for further processing by the electronic circuit. In order to respond to higher channel counts and transmission speed, the efforts of improving the performance of OPM have often focused on enhancing the performance of the optical part, i.e. the spectral element, which in turn resulted in a high design complexity and high manufacturing risks.

[005] Following an RHK report ("Vendors Must Adapt Products, Strategies to Stake a Claim in Crowded OPM Market", Insight, January 2002), one may classify OPMs into three groups: Type-I OPMs, Type-II OPMs, and Type-III OPMs. A Type-I OPM is a monitor capable of providing real-time measurements of power (P) for each DWDM channel. A Type-II OPM is a monitor capable of providing real-time measurements of power (P), central wavelength (λ), and a quantity similar to an optical signal-to-noise ratio (OSNR), i.e. a rough estimate of OSNR for each channel. A Type-III OPM is able, moreover, to predict indicators of the service quality provided by a WDM system such as the bit-error rate (BER) and Q-factor (Q). Currently, those indicators can be correctly measured only with out-of-service test equipment, using a known test sequence in place of the real signal. The determination of BER and Q therefore takes place in the electrical domain, after a signal received by the detector array is passed on to the electronic circuit. Obviously, this is an expensive, time-consuming and cumbersome method.

[006] Typically, in conventional applications, BER is determined by counting bits, a process which takes place in the time domain. Assuming a regular BER value in the order of 10-11, and assuming a tact speed of 1 GHz for the bit data flow, it is to be expected that during 1 second of data flow and bit counting one faulty bit is to be detected. To determine BER with a per mill accuracy, a testing time of about 26 hours is estimated.

[007] It would be highly advantageous to have at one's disposal alternative, and simpler monitoring methods for faster fault detection and localization. Optical domain methods, even if less accurate than electrical ones, can provide a fast, a simple, and an economical approach to reach this goal.

[008] It would be of further advantage to have at hand a system that allows for real-time determination of a real OSNR value, and BER or Q value from data representative of a real-world signal without the need for specific test signal sequences.

Object of the Invention

[009] It is therefore an object of the instant invention to provide a method and a system for real-time, in situ optical performance monitoring of a WDM system.

[0010] It is a further object of the instant invention to provide a method and a system for determining channel central wavelength, channel power, and channel OSNR from data representative of a light-signal spectrum, the light signal used in a WDM system.

[0011] It is yet a further object of the instant invention to provide a method and a system for extracting information about BER or Q from the data representative of the light-signal spectrum.

Summary of the Invention

[0012] In accordance with an aspect of the instant invention, there is provided a method for monitoring a quality of data transmission of at least one optical channel. The method comprises the steps of capturing a spectrum of a light signal transmitted on the at least one optical channel at an instance in time, providing a spectrum of a time-domain signal, performing an analysis of the spectrum to determine a quality of the light signal, and determine from the quality of the light signal a quality of data transmission.

[0013] In accordance with another aspect of the instant invention, there is provided a method for monitoring a quality of data transmission of at least one optical channel. The method comprises the steps of providing data representative of a plurality of spectra to a

processor for assessing a correlation between said spectra, determining from said correlation a quality of data transmission of the at least one optical channel.

[0014] In accordance with yet another aspect of the instant invention, there is provided a method for estimating BER or Q characterizing the quality of data transmission on at least one optical channel. The method comprising the steps of capturing a spectrum of a light signal transmitted on the at least one optical channel at an instance in time, performing an analysis of said spectrum to determine a quality of the light signal, and estimating BER or Q characterizing the quality of data transmission on the basis of the quality of the light signal, wherein that BER or Q is estimated absent a summation of bit errors over a period of time sufficient to provide a statistically valid estimate of BER or Q.

[0015] In accordance with an aspect of the instant invention, there is also provided a flash optical performance monitor (Flash-OPM) for monitoring a spectral quality of light received and for determining from changes in the spectral quality relative to a known spectral quality indicative of an acceptable signal, an estimate of signal quality. The flash optical performance monitor comprises a spectrometric transducer for performing a spectral decomposition of the light received, and for transforming the decomposed optical signal into electrical-domain data, a memory for storing advanced digital signal processing routines, and a processor in connection with the spectrometric transducer and with the memory. The processor receives the advanced digital signal processing routines and the electrical-domain data, and applies the advanced digital signal processing routines to those data.

Brief Description of the Drawings

[0016] A preferred embodiments of the instant invention will be described in conjunction with the following drawings, in which

[0017] Figure 1 displays a schematic diagram of a prior art optical channel performance monitor;

[0018] Figure 2 shows a flow diagram illustrating a method according to the instant invention;

[0019] Figure 3 displays a diagram illustrating the functionality of a neural network to be used for determination of OSNR, and BER or Q.

[0020] Figure 4 displays a diagram illustrating a method for BER or Q determination;

[0021] Figure 5 displays a diagram illustrating a method for calibrating the Flash-OPM for BER or Q determination;

[0022] Figure 6 shows a schematic diagram of a first embodiment of a flash optical performance monitor;

[0023] Figure 7 shows a schematic diagram of a second embodiment of a flash optical performance monitor; and

[0024] Figure 8 shows s schematic diagram of a third embodiment of a flash optical performance monitor.

[0025] The symbols used in the above-listed figures are defined in the next section.

Detailed Description of the Invention

[0026] The instant invention will now be described with reference to specific embodiments thereof. Of course, the invention is not restricted to a specific hardware device, but is to be utilized in connection with various hardware solutions. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to other embodiments and applications without departing from the spirit and the scope of the invention. Thus, the instant invention is not intended to be limited to the embodiments disclosed, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

[0027] In order to gain a better understanding of the instant invention, it is helpful to define and explain purpose and function of an optical performance monitor (OPM) in some detail. Considering conventional optical network performance monitoring, devices used typically contain a detection element that is responsive to the combination of all signal channels carried by a main signal stream, and that is operative to generate data containing

information of a collective power level provided by all channels. Such data generated in the electrical domain are not sufficient to provide detailed information of channel performance. For instance, if a power level of one of a plurality of channels of the main signal stream is decreased while a power level of another channel is increased, a total power level measured by such device typically remains constant, thereby providing an inaccurate indication of a monitored network performance. Thus, in order to monitor a condition of an individual channel in a DWDM network, performance monitoring is preferably carried out in the optical layer. An OPM constitutes an integrated spectrometric device at a module level operating in the optical layer, the device which is capable of monitoring the performance of all individual channels, and of providing rapid channel identification, i.e. P, λ, and OSNR measurements for each channel.

[0028] Several types of the OPM devices are available in the market, each of which addresses different functions and different purposes. A Type-I OPM and Type-II OPM are representative examples. The former measures only power P, while the latter usually measure P, λ, and OSNR for each channel. The Type-I OPM emphasizes the information, i.e. the power, at given channels, rather than monitoring wavelength and its variation. It commonly uses demultiplexing-type spectrometric transducers. Since a demultiplexing-type component, e.g. an AWG, gives a set of fixed discrete channels with a pre-defined frequency interval, i.e. channel spacing, such OPM is only able to provide power measurements at the wavelength positions corresponding to the DWDM channels. It is obvious that the measurements will be biased when there is thermal-wavelength drift of the spectral element. A type-II OPM is able to provide more network information than a type-II OPM since it not only measures power, but also monitors wavelength and its variation, as well as OSNR.

[0029] In Figure 1, a prior art schematic block diagram of an OPM is shown. A fractional portion of light power, typically 2%, is tapped from the mainstream optical signal running through the mainstream optical fibre 11, using a tap coupler 12. The purpose of tapping is monitoring the optical signal while keeping the properties of the main traffic unchanged. Since the tapped signal will not be added back to the mainstream data, there is little effect on the properties of the transmitted data, and the OPM thus

provides an almost non-invasive measurement. The weak signal tapped from the mainstream optical signal is then directed to an optical unit 13, by which the channelized wavelength components are separated. The optical unit 13 therefore performs a spectral decomposition of the optical signal; the results of that decomposition are detected by a detector array 14. The detector array 14 converts optical signals into electrical signals. The electrical signals are transmitted to the electronics circuitry 15 for processing and digital output.

[0030] It is not P, λ, and OSNR of each channel that is of prime interest of in-service monitoring of a DWDM system, but rather BER and Q. The conventional approach in determining BER makes use of out-of-service test equipment, and is time consuming and expensive. An obvious approach to in-service BER or Q reporting is a time-domain approach. It consists of tapping off a part of an optical signal, demultiplexing it through a tunable filter, detecting and then electrically regenerating it through an integrated receiver. However, this approach presents various drawbacks. It is an expensive and time-consuming method since it operates in a serial manner – channel by channel - using serial channel scanning and BER or Q processing. Further, BER or Q is mainly determined by an amount of integrated receiver noise, since the integrated receiver generates the format and the content of the data being transported before reaching a final destination. Also, shape and peak transmission of the tunable filter introduce signals distortions, such as chromatic dispersion, low isolation, and crosstalk, thus contributing to an increase in BER (decrease in Q) or a reduction in reliability.

[0031] The instant invention provides an approach to estimate BER and Q in the optical domain, as they would be recorded at the output of an ideal receiver connected to a monitored point of a network. It overcomes the above-listed drawbacks and provides a fast, simple and economical measurement technique for performance assessment in comparison to the electrical-domain classic approaches. It is applicable to in-service and out-of service approaches. Thus, the instant invention provides an approach to design a Type-III OPM called Flash-OPM.

[0032] A flow diagram illustrating a method according to the instant invention is depicted in Figure 2. In a first step 201, data $\{\tilde{y}_n \mid n = 1, 2, ..., N\}$ representative of the spectrum of a transmitted signal are acquired. Then, such parameters as P, λ, and OSNR for each channel, and possibly corresponding chromatic dispersion and polarization-related parameters, are extracted, step 202. In fact, the data representative of the spectrum in addition contain relevant information about propagation distortions, channels crosstalk and noise. In step 202, advanced digital signal processing (ADSP) routines are employed. Such routines are well known in the art, and are for example described in detail in US Pat. No. 5,991,023 to Morawski et al., issued November 23, 1999, and in US Pat. No. 6,002,479 to Barwicz et al., issued December 14, 1999. ADSP routines include a set of digital-signal-processing routines DSP-I, which is used to determine relevant parameters such as P, λ, and OSNR for each channel from $\{\tilde{y}_n\}$ data representative of the spectrum of an optical signal. In a step 203, those data are used to determine BER and Q values, by -- for example -- utilizing identified relationships between the BER or Q and the spectrum. In step 203, a set of digital-signal-processing routines DSP-II is used, being included in ASDP. In step 204, there is reported a real-time reliable in-service estimate of BER and Q, useful in a network monitoring system and compatible with the standard off-service method.

[0033] The method as illustrated in Figure 2 provides a number of advantages compared to traditional out-of-service BER-test techniques. The method according to the instant invention is an optical-layer testing method. The method is also an in-service method. A BER test of all channels is performed in parallel and thus simultaneously. The method provides a low-cost solution as well as a fast solution to the problem of service monitoring of DWDM networks. Test times, according to the method described in Figure 2, remain substantially constant as channel counts increase. Also, the described method does not depend on transmission protocol, on data format or on complex test signal generation.

[0034] The DSP-II routines, used in extracting useful BER and Q information, are constructed according to the following principles. A spectrometric transducer converts

input light into a set of data $\{\tilde{y}_n\}$ representative of a spectrum of this light. The spectrometric transducer is for example part of a Type-II OPM device, but it is not restricted to such devices and applications. An output-related discretisation of a wavelength axis is defined by a sequence $\{\lambda_n\}$ such that $\lambda_{\min} = \lambda_1 < \lambda_2 < \ldots < \lambda_{N-1} < \lambda_N = \lambda_{\max}$, where N is a number of individual photodetector elements. For example, using Type-II OPM having a detector array, such as the one described in Figure 1, N represents a number of photodiodes in the detector array. Thus, the average interval between wavelengths, in the given example equivalent to the distance two neighbouring photodiodes are adjusted to each other, is given by $\Delta\lambda = (\lambda_{\max} - \lambda_{\min})/(N-1)$. It is assumed that the data $\{\tilde{y}_n\}$ represent a spectrum of K channels combined in a DWDM system under consideration. A subsequence of data $\{\tilde{y}_n \mid n = N_{k,\min}, \ldots, N_{k,\max}\}$ is used for estimation of BER or Q, a quantity denoted with x, characterising a kth channel, $k = 1, \ldots, K$. Further, the length of this subsequence is variable, and amounts for example to 3, 4, 5, 6 or more elements. In the following, for the sake of simplicity, considerations are limited to one channel only, and the symbol $\{\tilde{y}_n\}$ is used for denoting this subsequence. A person of skill in the art is able to extend the concept with ease to any other number of channels.

[0035] BER depends on all the elements of a telecommunication channel. The spectrum of the transmitted signal contains more information on BER than any estimates of P, λ, OSNR that are possibly determined on the basis of the data $\{\tilde{y}_n\}$ representative of said spectrum. It contains, in particular, information on chromatic dispersion and polarization-related effects such as PMD. In order to extract from the data $\{\tilde{y}_n\}$ enough information to provide a meaningful estimate of BER or Q, it is possible to consider multiple algorithmic solutions, based both on statistical means of inference and on various methods of multidimensional approximation, including artificial neural networks.

[0036] In one method according to the instant invention, following a straightforward approach, a neural network is designed. A modus operandi of such neural network is

illustrated in the schematic diagram shown in Figure 3. An input set 301 consisting of the subsequence $\{\tilde{y}_n\}$ is provided to a neural network 300. When properly trained, the neural network responds with an estimate $\hat{x}$ 309 of x (BER or Q) on the basis of $\{\tilde{y}_n\}$. It is important for training the network that data $\{\tilde{y}_n\}$ stem from a low-resolution optical component. The sets of data preferably represent a telecommunication signal distorted in various ways by its propagation trough optical elements such as fibres, amplifiers, and filters.

[0037] In another method according to the instant invention, the problem of determining BER or Q is constructed in a broad context of algorithmic options, which are derived from ideas of quasi-dynamic measurand reconstruction being a well-established and well-recognised method in digital signal processing, as for example illustrated in the paper "The Role of Digital Signal Processing in Measurement Science", published in Measurement Science – A Discussion (Ohmsha Press Pub., Tokyo 2000, pp. 77-102). The problems of quasi-dynamic measurand reconstruction are distinctive by high redundancy of measurement information in raw measurement data $\{\tilde{y}_n\}$: the value of a scalar measurand x (BER or Q) is estimated on the basis of a subsequence of data representative of the channel spectrum the measurand is approximately related to. Consequently, implicit or explicit compression of data is present in any procedure for solving a problem of quasi-dynamic measurand reconstruction.

[0038] A general methodology for solving problems of quasi-dynamic measurand reconstruction consists of two steps: compression of the data $\{\tilde{y}_n\}$, i.e. transformation of the data $\{\tilde{y}_n\}$ into an estimate $\hat{\mathbf{p}}$ of a vector of informative parameters $\mathbf{p}$, $\{\tilde{y}_n\} \rightarrow \hat{\mathbf{p}}$, and subsequent estimation of the measurand on the basis of $\hat{\mathbf{p}}$, $\hat{\mathbf{p}} \rightarrow \hat{x}$. This methodology is illustrated in the schematic diagram shown in Figure 4. An input set 401 containing the subsequence $\{\tilde{y}_n\}$ is provided to a data compressor 402. The data compressor 402 compresses the subsequence $\{\tilde{y}_n\}$ to obtain a set 403 containing an estimate $\hat{\mathbf{p}}$, which is provided to a BER or Q estimator 405. When properly calibrated, the BER or Q estimator

405 responds with an output set 409 containing an estimate $\hat{x}$ of x, i.e. of BER or Q. A complexity of the method illustrated in Figure 4 depends on a number of informative parameters, i.e. the dimension of the vector $\hat{\mathbf{p}}$. The greater the number of informative parameters, the more time is required both for calibration and for BER or Q estimation.

[0039] The calibration of a Flash-OPM is an important step in the methodology described above. It is to be performed on the basis of reference data, which are structured as $\mathbf{D}^{\text{cal}} = \left\{\tilde{x}_\nu^{\text{cal}},\ \left\{\tilde{y}_{n,\nu}^{\text{cal}}\right\} \middle| \nu = 1, 2, \ldots, N^{\text{cal}}\right\}$. In Figure 5, a schematic diagram for a method of calibration is outlined. An input set 501 containing the subsequence $\left\{\tilde{y}_{n,\nu}^{\text{cal}}\right\}$ is provided to a data compressor 402. The data compressor 402 compresses the subsequence $\left\{\tilde{y}_{n,\nu}^{\text{cal}}\right\}$, and computes an estimate of a vector of informative parameters $\hat{\mathbf{p}}_\nu^{\text{cal}}$, corresponding to reference values $\tilde{x}_\nu^{\text{cal}}$, on the basis of $\left\{\tilde{y}_{n,\nu}^{\text{cal}}\right\}$ for $\nu = 1, 2, \ldots, N^{\text{cal}}$. The set 503 containing the parameters $\hat{\mathbf{p}}_\nu^{\text{cal}}$ is provided to a BER or Q estimator 505. The BER or Q estimator 505 responds with an output set 509 containing a datum $\hat{x}_\nu^{cal}$. In a data adjustor 504, the data $\hat{x}_\nu^{cal}$ and $\tilde{x}_\nu^{\text{cal}}$ are compared. The result of this comparison is provided as feedback to the data compressor 502 and the BER or Q estimator 505, where in turn this information is utilized in constructing an approximation of the relationship $\mathbf{p} \rightarrow x$ using a set of input-output pairs: $\left\{\hat{\mathbf{p}}_\nu^{\text{cal}}, \tilde{x}_\nu^{\text{cal}} \middle| \nu = 1, 2, \ldots, N^{\text{cal}}\right\}$.

[0040] A large variety of algorithms is possibly generated by combining various techniques of data compression with various types of approximators. For example, the following techniques of data compression are optionally used: principal component analysis, computation of inner products of the data $\{\tilde{y}_n\}$ and linearly independent sequences $\{e_{j,n}\}$ ($j = 1,\ldots, J$), approximation of the spectrum $y(\lambda)$ on the basis of $\{\tilde{y}_n\}$ using a parameterised function $\hat{y}(\lambda_n;\mathbf{a})$ with $\mathbf{a}$ being a vector of parameters, and computation of the moments of the spectrum $y(\lambda)$ on the basis of $\{\tilde{y}_n\}$. In the considered

case, an application-specific vector of informative parameters could contain estimates of P, λ, and OSNR, the estimates determined on the basis of $\{\tilde{y}_n\}$. The most evident candidate for the measurand estimator, i.e. the BER or Q estimator, is a neural network being a universal approximator. Alternatively, B-splines are to be considered as measurand estimators. A person of skill in art will be able to suggest further methods of data compression and final measurand estimation.

[0041] Referring now to Figure 6, a schematic representation of a first embodiment of the instant invention is shown. The embodiment represents a real-time, flash optical performance monitor (Flash-OPM). The Flash-OPM 600 includes an optical user interface 610, an optical performance monitoring (OPM) engine 660, and an electrical user interface 620. The optical user interface 610 receives an optical input signal, and directs the received signal to the OPM engine 660. The OPM engine 660 contains a spectrometric transducer 661, a DSP-I processing unit 662, and a DSP-II processing unit 663. The spectrometric transducer 661 is for analyzing the optical signal received from the optical interface 610, and for providing the data representative of the spectrum of a light signal to the DSP-I processing unit 662. For example, an OPM as described in Figure 1 is optionally used as the spectrometric transducer 661. The DSP-I processing unit 662 comprises a processor and a memory (not shown), in which effective ADSP algorithms are stored. The DSP-I processing unit 662 performs reconstruction of spectrum parameters using a non-linear and non-stationary approach, and provides estimates for □P, and OSNR. Optionally, the DSP-I processing unit 662 and DSP-I processing unit 663 compensate for variations in temperature, wavelength drifts, aging of the optical components, and the like. The DSP-II processing unit 663 comprises a processor and a memory (not shown), in which effective ADSP algorithms are stored. The DSP-II processing unit 663 analyses the data $\{\tilde{y}_n\}$ and provides an estimate for BER or Q, the estimate that is then provided to the electrical user interface 620. The electrical user interface 620 transfers the estimates of P, λ, OSNR, and BER or Q to the user that is assessing the performance of a particular channel, and to and monitor the quality of a signal transmitted on said channel.

[0042] Referring now to Figure 7, a schematic representation of a second embodiment of the instant invention is shown. The embodiment represents a real-time Flash-OPM which is adapted to provide data suitable for use in a special application related to performance monitoring, viz. controlling a digital gain equalizer (DGE). The Flash-OPM 700 includes an optical user interface 710, an OPM engine 770. The OPM engine 770 contains a spectrometric transducer 771, a DSP-I processing unit 772, and a DSP-III processing unit 774. The optical user interface 710, the spectrometric transducer 771, and the DSP-I processing unit 772 performs similar functionality as described for optical user interface 610, the optical component 661, and the DSP-I processing unit 662. The DSP-III processing unit 664 comprises a processor and memory (not shown), in which DSP algorithms are stored. The DSP-III unit processes the P, λ, and OSNR estimates according to information suitable for control of DGE. A person of skill in the art easily envisions further applications of DSP-type processing units. These applications are feasible, since the spectrum retrieved by the spectrometric transducer, such as 661 or 771, and processed by the DSP-I unit, such as the DSP-I units 662 or 772, inherently contain relevant and significant information characterizing the input light signal.

[0043] Referring now to Figure 8, a schematic representation of a third embodiment of the instant invention is shown. The embodiment represents a real-time, Flash-OPM, which is adapted to provide data suitable for use in DGE control applications. The Flash-OPM 800 includes an optical user interface 810, an OPM engine 880, and an electrical user interface 820. The OPM engine 880 contains a spectrometric transducer 881, a DSP-I processing unit 882, a DSP-II processing unit 883, and a DSP-III processing unit 884. The similar components function in a similar way as the components described in the context of the Flash-OPM 600 and the Flash-OPM 700. Flash-OPM 800 alternatively provides P, λ, OSNR, and BER or Q output to the user, and/or provides data output suitable for DGE control. The concept of a variable Flash-OPM is not restricted to the use of providing P, λ, OSNR, and BER or Q output and DGE output only, but is easily extended to other outputs suitable for optical telecom applications.

[0044] The data processing performed by a Flash-OPM, such as 600, 700, or 800, takes place within a time range of a few milliseconds. Flash-OPM allows for in situ monitoring

of an optical signal transmitted on a given channel, and for immediate measures to reroute an optical signal to an alternative channel, once a faulty BER or Q value is detected. Assuming a response time of the Flash-OPM of 5 milliseconds, and a data flow rate of 1GHz, a data buffer of 640 kB is sufficient to ensure that no data is lost during the detection of a faulty BER or Q value and rerouting of an optical signal. By shifting the determination of BER or Q values from the time domain into the optical domain, a continuous, real-time quality assessment of an optical channel is possible, and it is further possible to route data transmission without a significant loss of information.

[0045] Although the present invention has been described with respect to specific embodiments thereof, various changes and modifications are optionally carried out by those skilled in the art without departing from the scope of the invention. Therefore, it is intended that the present invention encompass such changes and modifications as fall within the scope of the appended claims.

What is claimed is:

1. A flash optical performance monitor for monitoring a spectral quality of light received and for determining from changes in the spectral quality relative to a known spectral quality indicative of an acceptable signal, an estimation of signal quality, the flash optical performance monitor comprising:

a spectrometric transducer element for performing a spectral decomposition of the light received, and for transforming the decomposed optical signal into electrical-domain data;

a memory for storing advanced digital signal processing routines; and

a processor in connection with the wavelength optical unit and with the memory, the processor for receiving the advanced digital signal processing routines and the electrical-domain data, for applying the advanced digital signal processing routines to the electrical spectral data.

2. A flash optical performance monitor according to claim 1,

wherein the advanced digital signal processing routines include routines for performing the steps of determining a set of data $\{y_n \mid n = 1, ..., N\}$ representative of said electrical spectral data, and obtaining an estimate $\hat{x}$ of a measurand x from the set of data $\{y_n \mid n = 1, ..., N\}$, the measurand x describing a quality of the light received.

3. A flash optical performance monitor according to claim 2;

wherein the estimate $\hat{x}$ is determined by a comparison of the set of data $\{y_n \mid n = 1, ..., N\}$ with an ideal set of data.

4. A flash optical performance monitor according to claim 3,

wherein the comparison is performed using a processor for computing the estimate $\hat{x}$ from an existing correlation of the measurand x and the set of data $\{y_n \mid n = 1, ..., N\}$.

5. A flash optical performance monitor according to claim 4,

wherein the processor for computing the estimate $\hat{x}$ from an existing correlation of the measurand x and the set of data $\{\tilde{y}_n \mid n = 1, ..., N\}$ is a neural network.

6. A flash optical performance monitor according to claim 3,

wherein the comparison uses reference calibration data, the reference calibration data being structured as $\tilde{D}^{cal} = \{\tilde{x}_\nu^{cal}, \{\tilde{y}_{n,\nu}^{cal}\} \mid \nu = 1, 2, \ldots, N^{cal}\}$.

7. A flash optical performance monitor according to claim 1,

wherein a quality of data transmission by said light is obtained from the spectral quality of said light.

8. A flash optical performance monitor according to claim 7,

wherein a quality of data transmission is characterized by a quality factor Q.

9. A flash optical performance monitor according to claim 7,

wherein a quality of data transmission is characterized by a bit-error rate BER.

10. A method for monitoring a quality of data transmission of at least one optical channel, the method comprising the steps of:

capturing a spectrum of a light signal transmitted on the at least one optical channel at an instance in time;

providing a spectrum of a time-domain signal;

performing an analysis of the spectrum to determine a quality of the light signal; and

determine from the quality of the light signal a quality of data transmission.

11. A method for monitoring a quality of data transmission according to claim 10, wherein the quality of the data transmission describes a bit-error rate BER of the data transmission.

12. A method for monitoring a quality of data transmission according to claim 10,

wherein the quality of the data transmission describes a quality factor Q of the data transmission.

13. A method for monitoring a quality of data transmission according to claim 10,

wherein the step of spectrum analysis to determine a quality of the light signal comprises the steps of:

performing a spectral decomposition of the light signal;

determining a set of data $\{y_n \mid n = 1, \ldots, N\}$ representative of a result of said spectral decomposition; and

obtaining an estimate $\hat{x}$ of a measurand x, x being either one of BER and Q, from the set of data $\{y_n \mid n = 1, \ldots, N\}$, the measurand x describing a quality of the light signal.

14. A method for monitoring a quality of data transmission according to claim 13;

wherein the estimate $\hat{x}$ is determined by a comparison of the set of data $\{y_n \mid n = 1, \ldots, N\}$ with an ideal set of data.

15. A method for monitoring a quality of data transmission according to claim 14,

wherein the comparison is performed using a processor for computing the estimate $\hat{x}$ from an identified correlation of the measurand x and the set of data $\{y_n \mid n = 1, \ldots, N\}$.

16. A method for monitoring a quality of data transmission according to claim 15,

wherein the processor for computing the estimate $\hat{x}$ from an identified correlation of the measurand x and the set of data $\{y_n \mid n = 1, \ldots, N\}$ is a neural network.

17. A method for monitoring a quality of data transmission according to claim 14,

wherein the comparison uses reference calibration data, the reference calibration data being structured as $D^{\mathrm{cal}} = \{x_\nu^{\mathrm{cal}}, \{y_{n,\nu}^{\mathrm{cal}}\} \mid \nu = 1, 2, \ldots, N^{\mathrm{cal}}\}$.

18. A method for monitoring a quality of data transmission according to claim 10,

wherein the quality of more than one optical channel is monitored by a same process of spectrum analysis.

19. A method for monitoring a quality of data transmission according to claim 11,

wherein the quality factor Q of at least one optical channel is monitored over a period of time, and wherein an indication signal is provided, the indication signal indicative of at least one optical channel on which the quality factor Q has varied from an acceptable value to an unacceptable value.

20. A method for monitoring a quality of data transmission according to claim 19,

wherein the indication signal is provided within one second after the quality factor Q has varied from an acceptable value to an unacceptable value.

21. A method for monitoring a quality of data transmission according to claim 12,

wherein the bit-error rate BER of at least one optical channel is monitored over a period of time, and wherein an indication signal is provided, the indication signal indicative of at least one optical channel on which the bit-error rate BER has varied from an acceptable value to an unacceptable value.

22. A method for monitoring a quality of data transmission according to claim 21,

wherein the indication signal is provided within one second after the bit error rate BER has varied from an acceptable value to an unacceptable value.

23. A method for monitoring a quality of data transmission of at least one optical channel, the method comprising the steps of:

providing a plurality of spectra to a processor for assessing a correlation between said spectra; and

determining from said correlation a quality of data transmission of the at least one optical channel.

24. A method for monitoring a quality of data transmission according to 23,

wherein the quality of the data transmission describes a quality factor Q of the data transmission.

25. A method for monitoring a quality of data transmission according to claim 23,

wherein the quality of the data transmission describes a bit error rate BER of the data transmission.

26. A method for monitoring a quality of data transmission according to claim 23,

wherein the correlation is established by use of a neural network.

27. A method for monitoring a quality of data transmission according to claim 23,

wherein the correlation is established by use of reference calibration data.

28. A method for monitoring a quality of data transmission according to claim 23,

wherein the quality of more than one optical channel is monitored by a same process of correlation.

29. A method for monitoring a quality of data transmission according to claim 24,

wherein the quality factor Q of at least one optical channel is monitored over a period of time, and wherein an indication signal is provided, the indication signal indicative of at least one optical channel on which the quality factor Q has varied from an acceptable value to an unacceptable value.

30. A method for monitoring a quality of data transmission according to claim 29,

wherein the indication signal is provided within one second after the quality factor Q has varied from an acceptable value to an unacceptable value.

31. A method for monitoring a quality of data transmission according to claim 25,

wherein the bit error-rate BER of at least one optical channel is monitored over a period of time, and wherein an indication signal is provided, the indication signal

indicative of at least one optical channel on which the bit-error rate BER has varied from an acceptable value to an unacceptable value.

32. A method for monitoring a quality of data transmission according to claim 31,

wherein the indication signal is provided within one second after the bit-error rate BER has varied from an acceptable value to an unacceptable value.

33. A method for estimating a bit-error rate BER of data transmission on at least one optical channel, the method comprising the steps of:

capturing a spectrum of a light signal transmitted on the at least one optical channel at an instance in time;

performing an analysis of said spectrum to determine a quality of the light signal; and

estimating from the quality of the light signal a bit-error rate BER of data transmission,

wherein the bit-error rate BER is estimated absent a summation of bit errors over a period of time sufficient to provide a statistically valid estimate of a bit-error rate BER.

34. A method for estimating a bit-error rate BER according to claim 33,

wherein the instance of time is less than a time period during which a number of bits are transmitted, within which an acceptable bit count will show at least one error.

35. A method for estimating a bit-error rate BER according to claim 34,

wherein the number of bits amounts to at least 10,000 bits.

36. A method for estimating a bit-error rate BER according to claim 33,

wherein the step of spectrum analysis to determine a quality of the light signal comprises the steps of:

performing a spectral decomposition of the light signal;

determining a set of data $\{y_n \mid n = 1, \ldots, N\}$ representative of a result of said spectral decomposition; and

obtaining an estimate $\hat{x}$ of a measurand x from the set of data $\{\tilde{y}_n \mid n = 1, ..., N\}$, the measurand x describing a quality of the light signal.

37. A method for estimating a bit-error rate BER according to claim 36;

wherein the measurand x is determined by a comparison of the set of data $\{\tilde{y}_n \mid n = 1, ..., N\}$ with an ideal set of data.

38. A method for estimating a bit-error rate BER according to claim 37,

wherein the comparison is performed using a processor for computing the estimate $\hat{x}$ from an existing correlation of the measurand x and the set of data $\{\tilde{y}_n \mid n = 1, ..., N\}$.

39. A method for estimating a bit-error rate BER according to claim 38,

wherein the correlation processor is a neural network.

40. A method for estimating a bit-error rate BER according to claim 37,

wherein the comparison uses reference calibration data, the reference calibration data being structured as $\tilde{D}^{\mathrm{cal}} = \{\tilde{x}_\nu^{\mathrm{cal}}, \{\tilde{y}_{n,\nu}^{\mathrm{cal}}\} \mid \nu = 1, 2, \ldots, N^{\mathrm{cal}}\}$.

41. A method for estimating a bit-error rate BER according to claim 33,

wherein the bit-error rate BER of more than one optical channel is estimated by the same process of spectrum analysis.

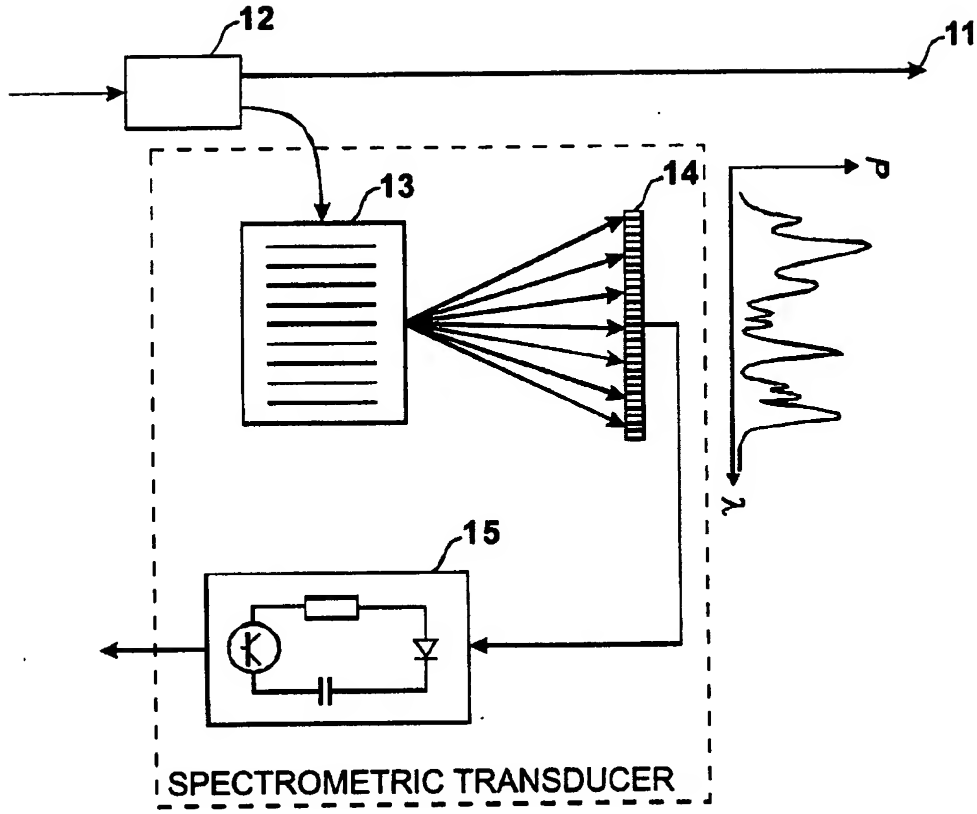


Figure 1

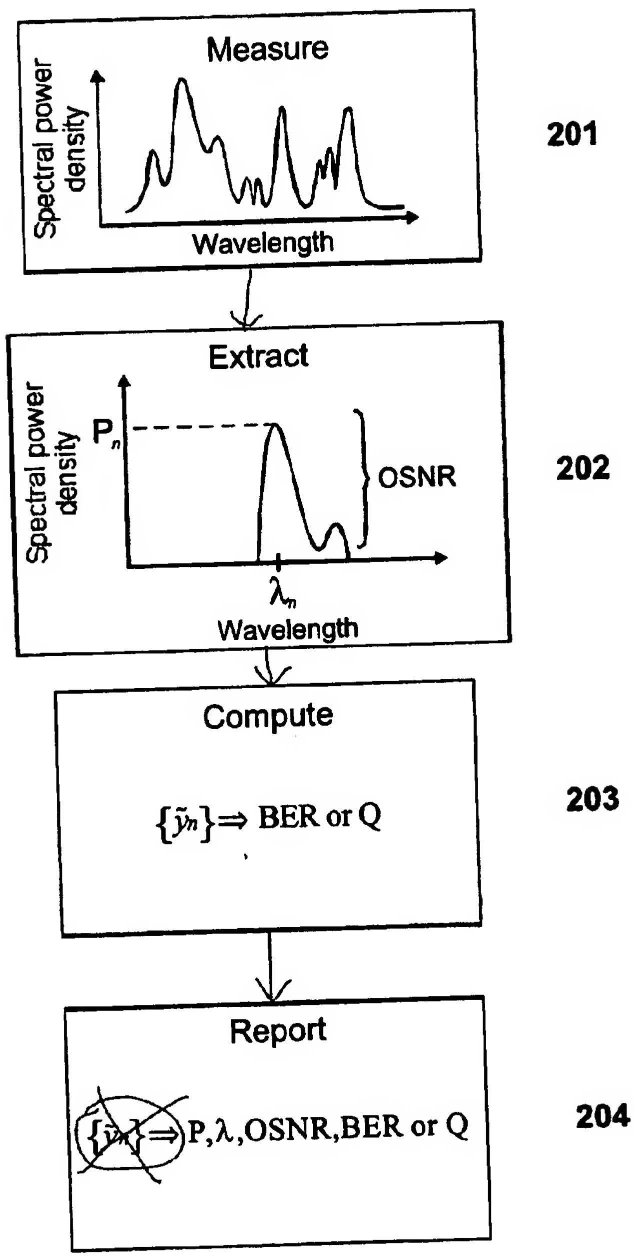
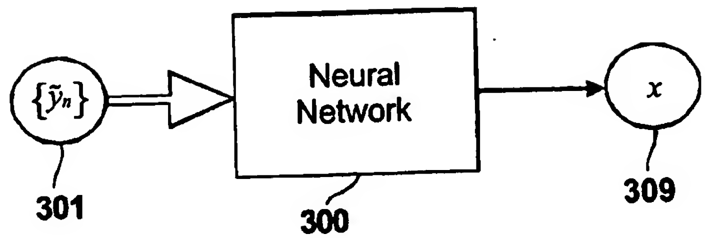

Measure
Spectral power density
Wavelength
201
Extract
Spectral power density
P_n
OSNR
λ_n
Wavelength
202
Compute
$\{\tilde{y}_n\} \Rightarrow$ BER or Q
203
Report
$\cancel{\{\tilde{y}_n\} \Rightarrow}$ P,λ,OSNR,BER or Q
204

Figure 2



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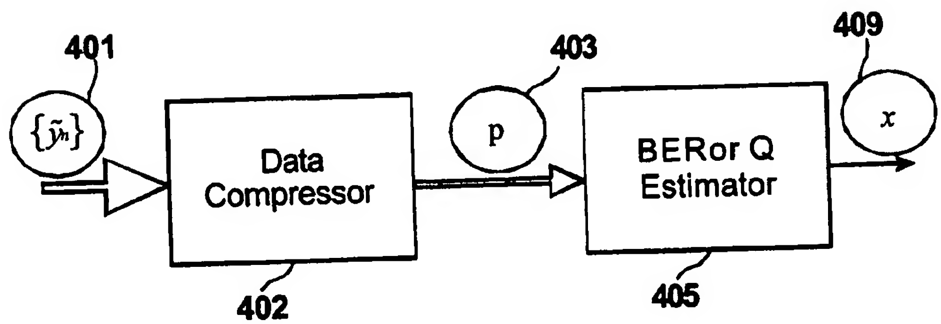


Figure 4

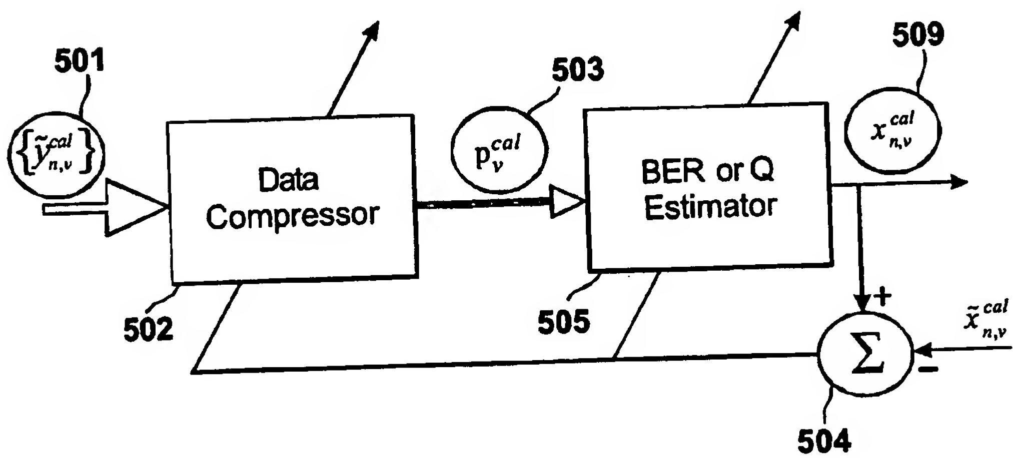
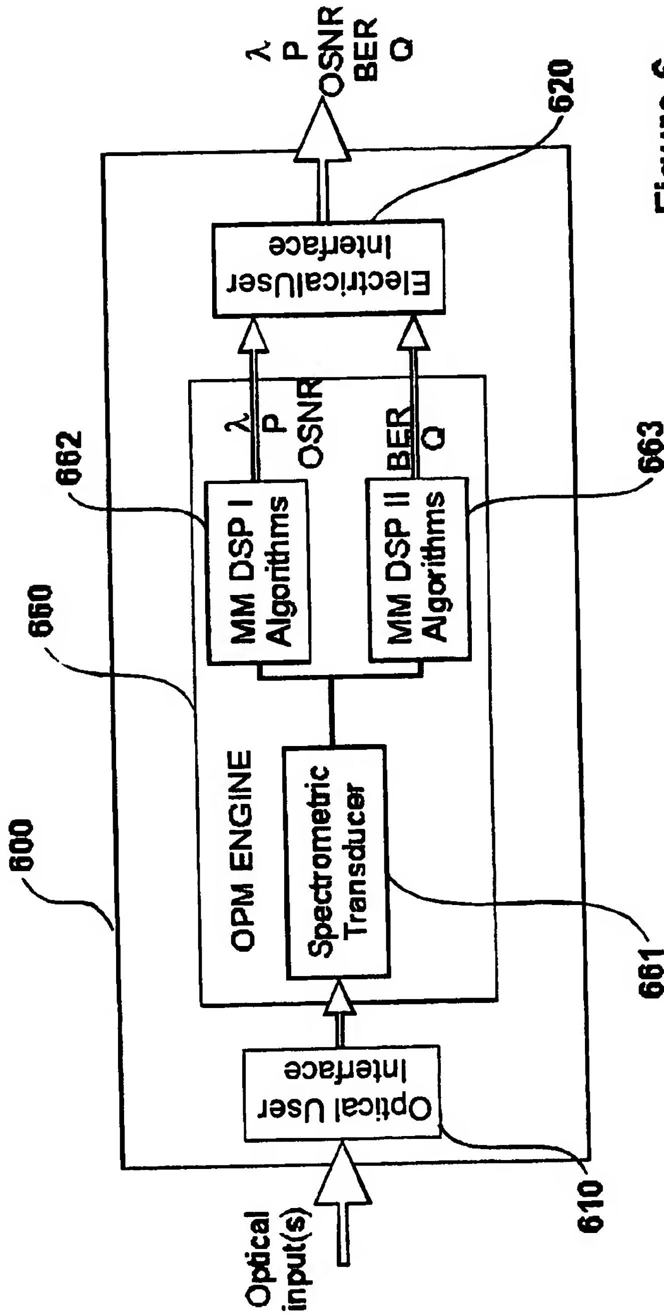


Figure 5


Optical input(s)
Optical User Interface
OPM ENGINE
Spectrometric Transducer
MM DSP I Algorithms
MM DSP II Algorithms
λ
P
OSNR
BER
Q
ElectricalUser Interface
λ
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600
610
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662
663

Figure 6

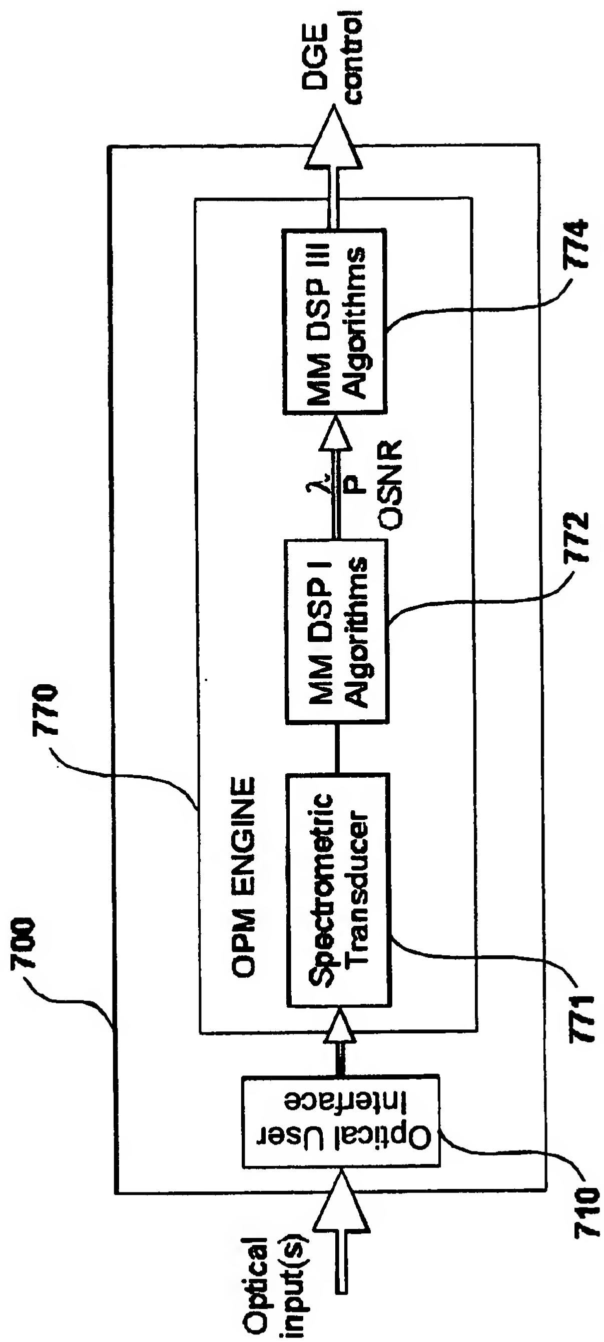
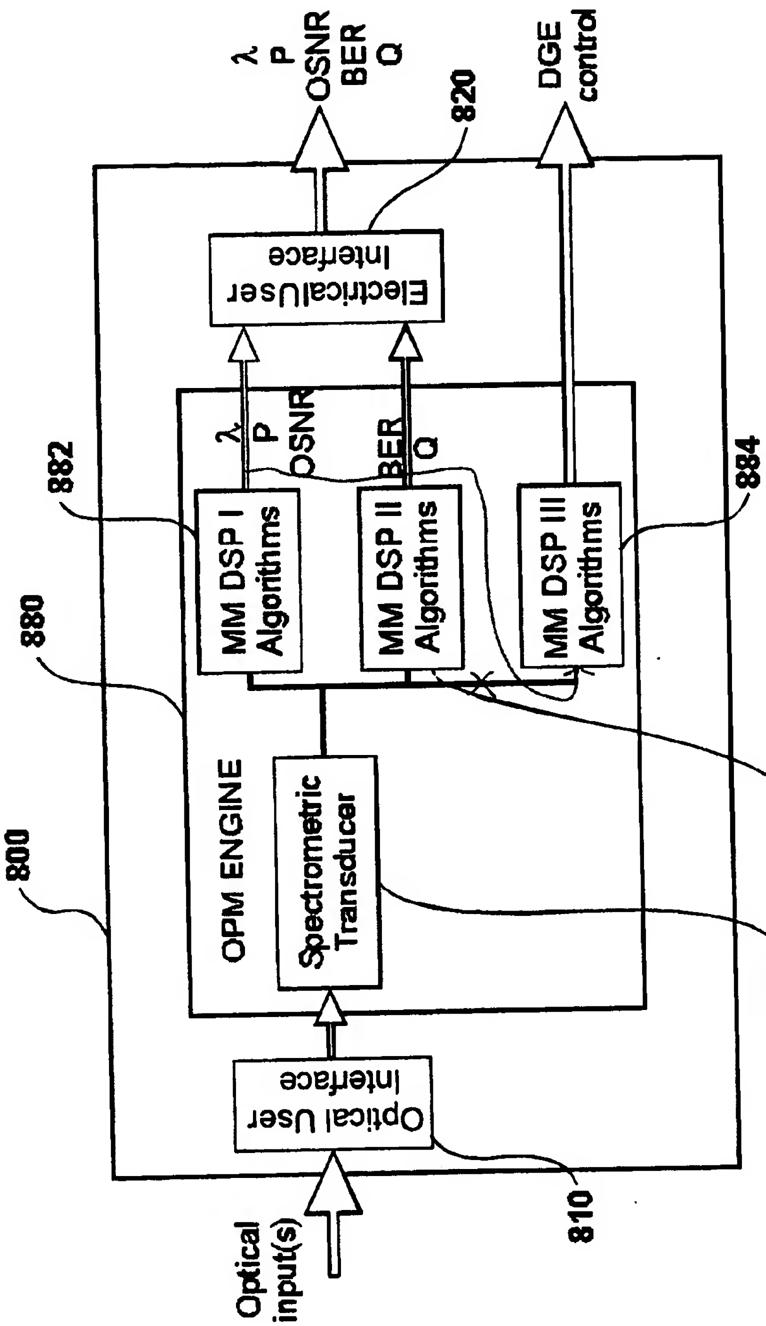

Optical input(s)
Optical User Interface
Spectrometric Transducer
OPM ENGINE
MM DSP I Algorithms
λ
P
OSNR
MM DSP III Algorithms
DGE control
700
710
770
771
772
774

Figure 7


Optical input(s)
Optical User Interface
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OPM ENGINE
Spectrometric Transducer
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MM DSP I Algorithms
882
MM DSP II Algorithms
MM DSP III Algorithms
884
883
λ P OSNR
BER Q
ElectricalUser Interface
820
λ P OSNR BER Q
DGE control

Figure 8